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BACK-SCATTERED ECHOES FROM IRREGULARITIES IN THE F REGION

by

B.R. Clemesha.

ABSTRACT

This report describes a number of experiments which were designed to investigate F region irregularities by means of the back-scatter technique, are described. The experimental techniques are described briefly, and the results given in detail. The results show the seasonal and nocturnal variations in the occurrence of irregularities which scatter 18 Mc/s. signals, the size and drift velocity of patches of irregularities, the height at which the irregularities occur, and the the motion of the irregularities, as opposed to the motion of the patch. The results are discussed in the light of information obtained by other workers using different techniques.

A

BACK-SCATTERED ECHOES FROM IRREGULARITIES IN THE F REGION.

1. Introduction

The experiments described in this report were designed to investigate the irregularities in the F region which are associated with equatorial type spread F. The spread F which is observed at equatorial latitudes varies in its appearance during the night (Lyon, Skinner and Wright, 1961), but may be divided into two basic types, which have been termed equatorial type and temperate latitude type respectively, the former occurring chiefly before midnight, and the latter mainly after midnight. Calvert and Cohen (1961) have shown that all of the equatorial type spread F configurations observed on ionograms may be synthesised by ray tracing, assuming one or more patches of irregularities which may be situated below, near to, or above the height of maximum F region ionisation, and which scatter in the east-west vertical plane. Temperate latitude type spread F has been attributed to 'waveguide' scattering in the north south vertical plane, by Pitteway and Cohen (1961).

Whilst the ionosonde method of studying spread F has provided valuable data as far as its occurrence and geomorphology are concerned, the ionosonde is not very well suited to a study of the detailed behaviour of the irregularities which cause spread F. As it is clear, both from experimental evidence, and on theoretical grounds, that some of the irregularities which produce equatorial type spread F should be capable of scattering signals with frequencies well above the critical frequency of the night-time F layer, it was decided to carry out an investigation of F region irregularities using a back-scatter radar operating on a frequency of 18 Mc/s. The advantages of such an equipment over the normal ionosonde are as follows: (i) By operating at a fixed frequency it is possible to use aerials of fairly high gain, thus increasing the system sensitivity considerably over that of a normal ionosonde.

(ii) The use of a fixed frequency enables a directional aerial to be used. (ii) Operating above the critical frequency with a directional aerial removes much of the ambiguity in determining the ray path taken by the signal in travelling to and from the irregularities which scatter it. (iv) Soundings may be continuous, rather than intermittent as with the ionosonde.

The equipment used for the experiments to be described in the following pages consisted basically of an 18 Mc/s. transmitter of 1 kW. peak power, 300 microsecond pulse duration, and 16-2/3 c/s. repetition frequency, and a pulse modified receiver having a bandwidth of approximately 6 Kc/s. The aerial used was a three element Yagi tuned for 18 Mc/s., mounted approximately half a wavelength above the ground, and rotatable about three mutually perpendicular axes by remote control, in such a way that the aerial could be pointed at any part of the sky with any direction of polarisation. The same aerial was used both for transmitting and receiving by means of a T/R switch.

Preliminary observations were made with the above equipment using an A scan display of echoes with range markers at 1 mS. intervals. The results from these observations indicated that a method of making a permanent record of the observed echoes was required, and so a P.P.I. display system with photographic recording was incorporated into the equipment. By means of suitable programming equipment it was arranged that P.P.I. photographs were taken at predetermined intervals, and at predetermined aerial elevations (the aerial elevation refers to the vertical angle from the horizontal of the axis of the Yagi); this equipment was fully described in Technical Note No. 4 (Clemesha, 1962). At a later date further equipment was added to enable continuous range versus time recordings to be made, and the doppler shift of the returned echoes to be measured.

2. Back-scattered echoes from F region irregularities.

When the equipment briefly described above was first set up it was noted that during the period 1900 to 2200 G.M.T. there occurred, at a range of between 400 and 1500 Km., a type of echo

which could not be attributed to any of the mechanisms responsible for echoes normally observed on back-scatter sounders. The usual purpose of a back-scatter sounder is to measure the skip distance, for normal ionospheric propagation at oblique incidence, by observing the echo due to ground back-scattering of a signal which has been reflected from the ionosphere, i.e. a signal which has been transmitted by the sounder, reflected by the ionosphere at oblique incidence, scattered by the ground, and has retraced the same path back to the sounder; the characteristics of the abnormal echoes observed between 1900 and 2200 G.M.T. were such that they could not have been caused by this mechanism. Whereas the normal back-scatter echoes are spread in range, often over a distance of more than 500 Km., the abnormal echoes referred to above were usually relatively sharp echoes, with a range spread of about 150 Km. It was also observed that for echoes with ranges of less than about 800 Km. the aerial elevation giving the strongest signal varied rapidly with range, and that echoes from about 400 Km. were strongest when the aerial was pointing vertically upwards. In the light of the observations described above it was clear that the echoes being observed were caused by direct back-scatter from patches of irregularities situated at a height of about 400 Km. in the F region. The following pages constitute a description of three experiments designed to obtain more information about the patches of irregularities, and the results of these experiments.

2.1 The P.P.I. measurements.

The recording of 18 Mc/s. back-scatter echoes, using a P.P.I. display, was commenced at the end of April, 1962, and, as at this stage little was known about the occurrence of direct back-scatter, the equipment was arranged to take one record every hour during the day (one P.P.I. sweep is completed in slightly less than one minute), every half hour from 1800 G.M.T. to midnight, and every quarter hour from 1900 to 2200 G.M.T., this last period being when the echoes were expected to occur most frequently. The aerial

elevation for these runs was fixed at 30° to the horizontal, in which position the sounder, although having a maximum sensitivity at an angle of about 15°, was sensitive to echoes from near horizontal to vertical angles of arrival. In addition to the runs at 30° elevation the sounder was programmed to take a series of four consequtive runs at aerial elevations of 5, 30, 60 and 85 degrees every hour from 1900 G.M.T. till midnight, the intention of these runs being to make it possible to distinguish between echoes originating in direct back-scatter from the F region, and ground back-scatter via sporadic E, by enabling an approximate determination of the angle of arrival of the echo signal to be made.

Fig. 1 shows some typical examples of P.P.I. records. In Fig. 1a, taken at 1200 G.M.T., normal ground back-scatter via F region reflection is visible at a range of about 1200 to 1500 Km. in all directions except north (it has been noted that in many of the records taken at Accra the range of echoes is less to the south than to the north, and that often no echo is visible to the north at all; this phenomenon is attributed to the effect of the equatorial anomaly, Accra being some 500 Km. to the south of the magnetic equator, the F region electron densities seen to the north should frequently be less than those to the south). Fig. 1b, taken at 2130 G.M.T., shows echoes at considerably shorter ranges than that of the normal ground back-scatter echo which is also present, it is these echoes which are attributed to direct back-scatter from the F region. In Fig. 1b the echo with the shortest range shows equal signal intensity from all directions, this echo is from a patch of irregularities vertically above the sounder at a height of 375 Km. The echo to the west has a slant range of 900 Km., and the echo to the east has a slant range of 550 Km., it will be noted that for these two echoes, maximum signal strength is obtained from magnetic rather than geographic east and west (in Fig. 1 geographic and magnetic north are indicated by N and H respectively). As well as the normal ground back-scatter at a range of about 1200 Km., and the direct back-scatter referred to

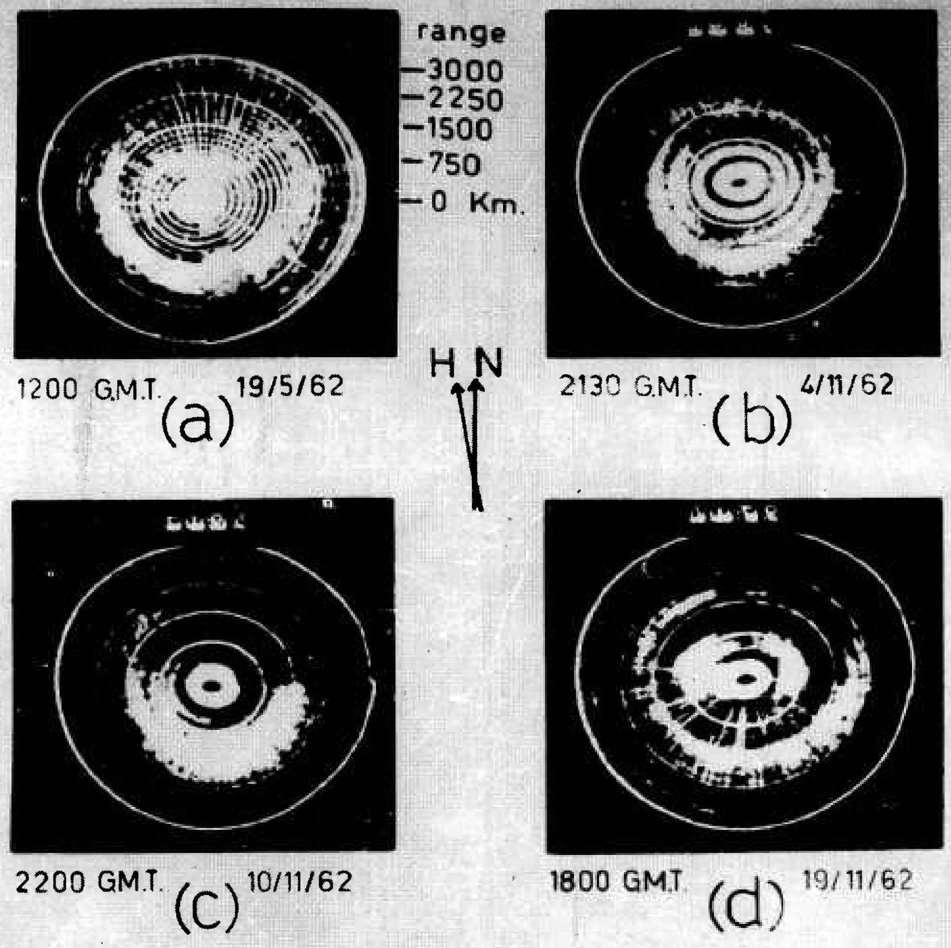

Fig. 1. (a) Ground back-scatter via F region. (b) Direct back-scatter. (c) Spread echoes. (d) Es scatter.

above, a third thpe of echo is present on the P.P.I. record shown in Fig. 1b, this echo is at a range of 1000 Km. to the south-east, and is similar in appearance to the direct back-scatter echoes, echoes of this type are fairly frequently observed in the south-east or south-west, and it has been noted that their azimuth swings round towards the south some time after they are first observed. These south-east or south-west echoes usually occur between 2100 and 2230 G.M.T., and only on nights when direct back-scatter is observed to the east and west; no investigation of them has yet been made. Another type of echo which is occasionally observed during the evening hours is the west, east, south-east, or south west, is illustrated in Fig. 1c, this type of echo frequently shows a range spread of up to 1000 Km.; again an investigation of this type of echo has yet to be made. Ground back-scatter via Es patches is sometimes observed, both during the day and the night, and as the appearance of such echoes (Fig. 1d) is considerably different from that of direct back-scatter echoes it was found unnecessary, in order to distinguish between Es and direct back-scatter, to continue to take routine P.P. records at different elevation angles.

The P.P.I. measurements were discontinued in June, 1962, and recommenced in August, since when measurements have continued to date. The measurements made between April and June, 1962, were intended as a preliminary investigation of direct back-scatter, and on the basis of these measurements further experiments were planned.

2.2. The range versus time measurements.

It was observed that echoes present on more than one of a series of P.P.I. records appeared to change in range in a systematic manner, indicative of a drift of the patch of irregularities towards the east. In order to investigate this phenomenon

more closely it would have been possible to take records at more frequent intervals, but it was decided that a more convenient technique would be to record a continuous range versus time display for a fixed aerial direction. Consequently it was arranged that the rest position of the aerial between P.P.I. sweeps should be such that it pointed towards the east or the west, and by photographing an intensity modulated line time base with a continuous motion camera, range/time records of the type illustrated in Fig. 2 were obtained.

In the first part of Fig. 2, where up until 2000 G.M.T. the aerial is facing east, the echo furthest from the origin is the ground back-scatter echo at a range of 1500 Km., and the echoes at closer ranges which increase with time are the result of direct back-scatter. After 2000 G.M.T. the aerial is facing west, and, as may be seen from Fig. 2 the range of direct back-scatter echoes now decreases with time. From the slope of the traces it is possible to determine a line of sight velocity for the patches of irregularities responsible for direct scatter, velocities determined in this manner are found to be approximately 100 metres per second, both for patches approaching the sounder from the west, and for patches travelling away from the sounder to the east. As the line of sight velocities to the east and to the west are about the same magnitude, but opposite in direction, it may be assumed that the drift is horizontal to a first approximation. The velocities derived from the range/time records are, of course, east-west components of velocity only, the experiment provides no information about any north-south velocity which might exist. Further results from this experiment will be given in S ction 3.

2.3 <u>The doppler shift measurements</u>.

The range/time measurements provide information about the drift velocity of a patch of irregularities, but as there is no reason to suppose that individual irregularities move with the same velocity as the patch, it is important to try to measure the velocity

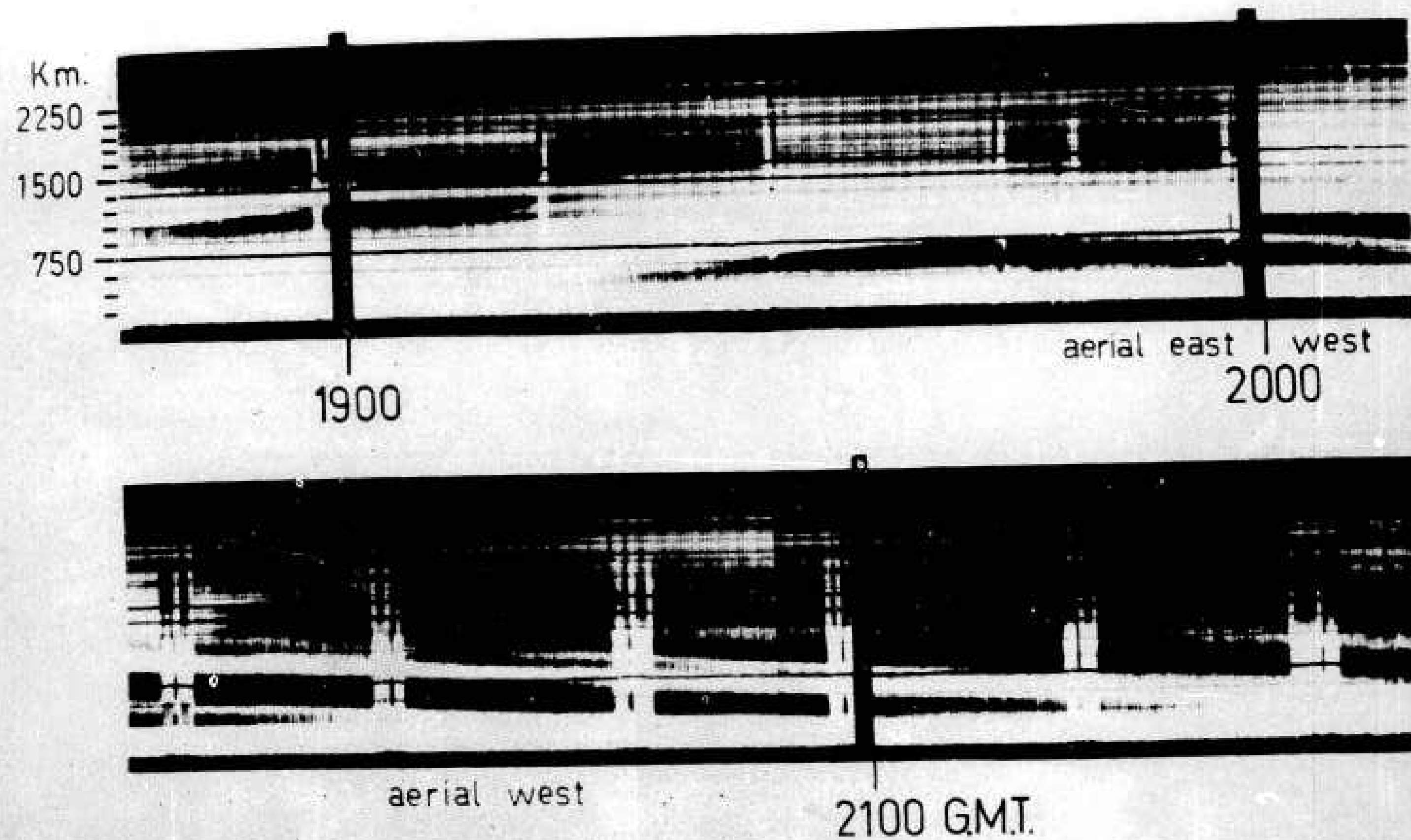

Fig. 2. Range versus time record of direct back-scatter.

of the irregularities themselves. As it is the individual irregularities which scatter radio waves, any component of velocity which they have in the direction of the sounder must produce a doppler shift of the sounder frequency, and hence, by measuring the doppler shift of the echo pulse it is possible to determine the line of sight velocity of the irregularities.

The technique used for measuring doppler shift was basically to mix the returned signal (separated from other signals and noise by means of a suitable gating circuit) with a reference signal, the frequency of which could be varied by a small amount from that of the transmitted signal. In this manner the frequency spectrum of the echo signal was obtained by sweeping the reference signal over a range of a few hundred cycles per second, passing the resulting beat note through a filter of approximately one cycle per second bandwidth tuned to 50 c/s. (a harmonic of the pulse repitition frequency), and recording the amplitude of the 50 c/s. signal on a pen recorder. In practice the problem is complicated by the high degree of stability required in the transmitted and reference frequencies, this is overcome by deriving the reference frequency from the transmitted frequency after both the transmitted and received frequencies have been brought down to a convenient intermediate frequency by means of coherent frequency changers. In order to provide a frequency shift reference some of the transmitted signal is permitted to enter the mixing circuit, but as the pulse modulated signal consists of carrier and sidebands of almost equal amplitude, at least for the first hundred sideband harmonics, it is not possible to distinguish between the carrier and the sidebands, or any particular sideband and another sideband, the result of which is that it is not possible to tell whether the doppler shifted echo frequency is above or below the transmitted frequency. In order to resolve this ambiguity a few measurements were made with a pulse repetition frequency of 25 c/s. as well as the normal measurements at 16-2/3 c/s., each measurement gives two

possible doppler shifts, one positive and the other negative, but only one of each pair is the same, and this is the correct shift. Having made a few determinations of the direction of the doppler shift in this manner, and obtained consistent results, it was found unnecessary to determine the shift unambiguously for all measurements.

An example of a typical frequency spectrum, obtained in the manner described above is shown in Fig. 3. In Fig. 3 the narrow lines are the sideband harmonics of the transmitted signal, and the irregular deflections covering a range of some six cycles per second are the echo signal. The irregular nature of the spectrum of the echo signal is probably due to the fact that the apparatus only examines one 1 c/s. wide band of frequencies at a time, and hence the integration time for a single frequency is short, in order to integrate the signal within a narrow frequency range over a long period a multi-channel spectrum analyser is required, and such equipment was unfortunately not available.

3. The results.

3.1 Nocturnal variation in the occurrence of direct back-scatter.

The P.P.I. records of direct back-scatter were reduced by scaling the direction (east or west), range, and width of each echo trace on each of the P.P.I. records taken. From the range of an echo, and the time at which it was observed, the local time at the source of the echo was determined, and all the echoes observed during the September to December, 1962, then divided into half hour time groups; the total number of echoes observed in each group is shown in the histogram of Fig. 4a. In examining a sequence of P.P.I. records taken at 15 minute intervals it is not always possible to distinguish between an echo which has persisted from one record to the next, and two different echoes which have similar range and direction, Fig. 4a therefore shows the proportionate number of echoes present at a given local time rather than the number of patches formed at that time. From the continuous records of range versus time it is possible to observe the growth and decay

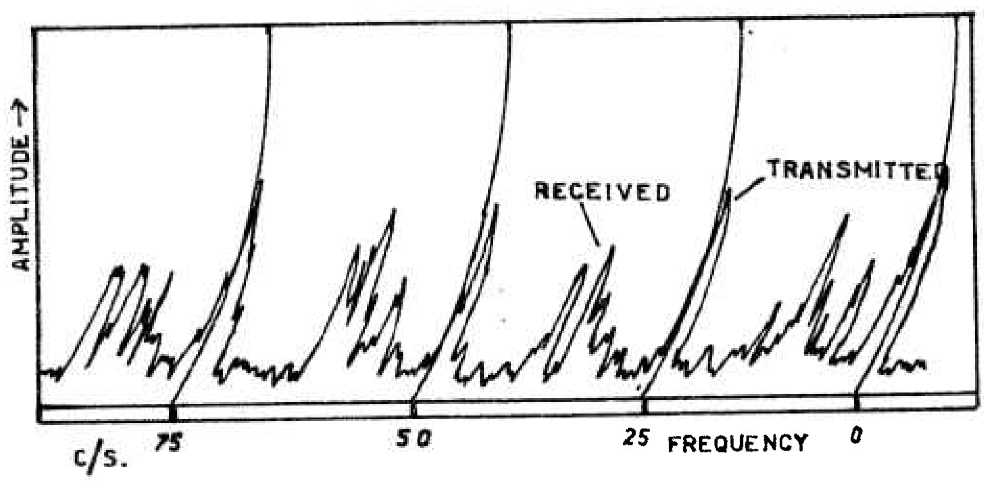

FIG.3. PART OF THE FREQUENCY SPECTRUM OF TRANSMITTED AND RECEIVED SIGNALS.

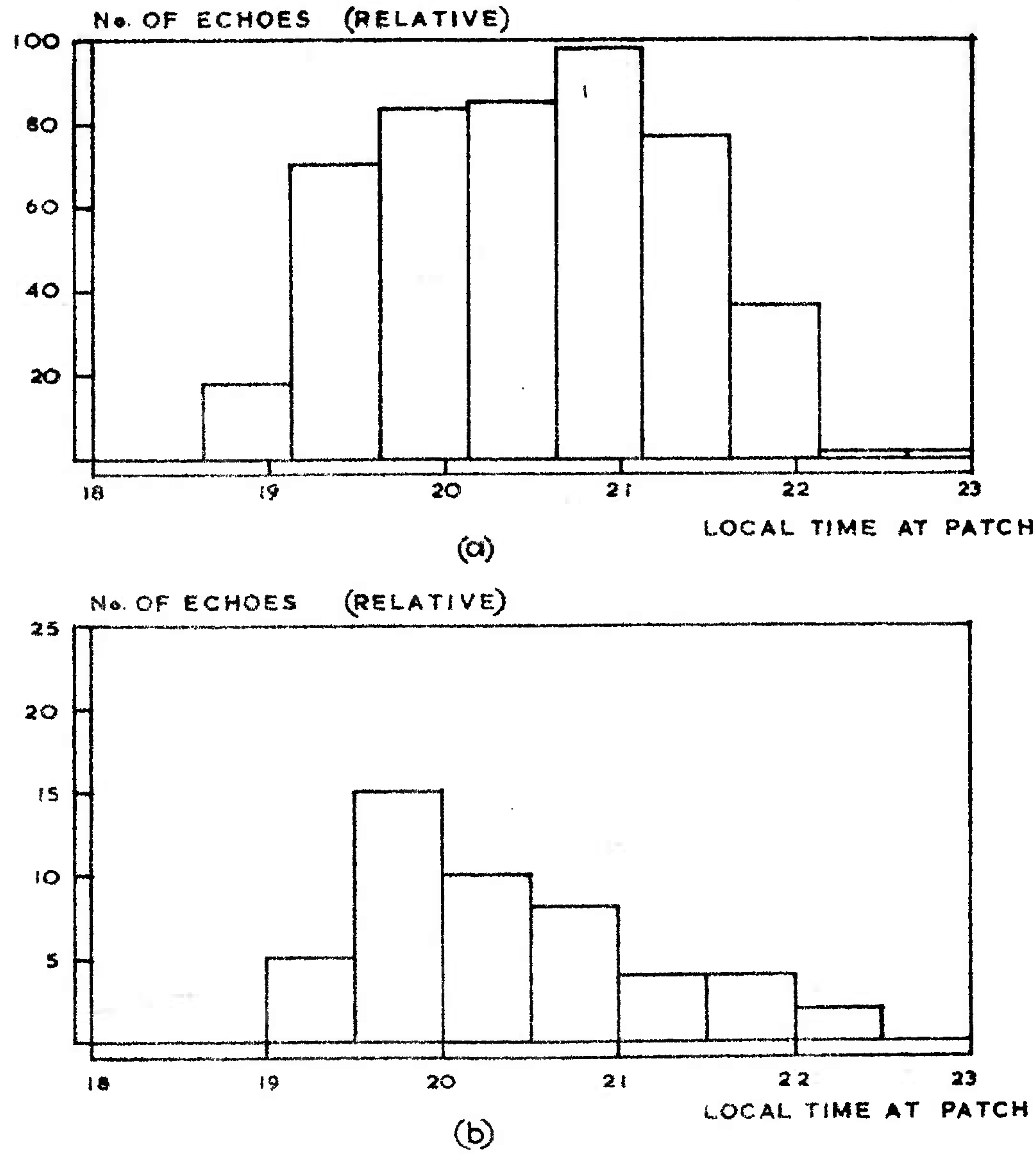

FIG. 4. (a) NOCTURNAL VARIATION IN OCCURENCE OF DIRECT BACK-SCATTER ECHOES.

(b) NOCTURNAL VARIATION IN RATE OF ECHO COMMENCEMENT.

of each echo, enabling the historam cf time of commencement of echoes shown in Fig. 4b to be constructed. Fig. 4a shows that most echoes are observed during the period 1900 to 2200 local time, very few echoes being observed outside of these limits. The distribution of times of commencement of echoes is somewhat different, showing that the rate of echo commencement is greatest at 1930 to 2000 local time, the increase between 1900 and 2000 being rapid, and the decay after 2000 being comparatively slow. Only on one occasion were echoes observed after 2300, when they persisted until 0100.

3.2 Seasonal variation in the occurrence of direct back-scatter.

When measurements were first commenced in April, 1962, direct back-scatter was observed on about fifty per cent of nights on which observations were made, by June the frequency of occurrence had dropped to less than ten per cent. Unfortunately it was necessary to discontinue the experiment in June, and not possible to recommence measurements until the end of August, however, the general impression obtained was that direct back-scatter occurred most frequently during the equinox period. The measurements made since August tend to substantiate this impression, although of course, a full year's measurements will be required before it can be definitely stated than an equinoctial maximum exists. The period from August 25th, 1962 to January 31st, 1963 has been divided into periods of two weeks, and a scattering index, proportional to the total number of echoes observed during a period calculated for each; the histogram of Fig. 5 shows how this scattering index has varied over the period during which measurements have been made.

3.3 Correlation of direct back-scatter with spread F.

Vertical incidence ionograms taken at Accra are available from October 28th, 1962 onwards, and hence it has been possible to make a day to day comparison between the occurrence of spread F and direct back-scatter. Such a comparison has been made on the

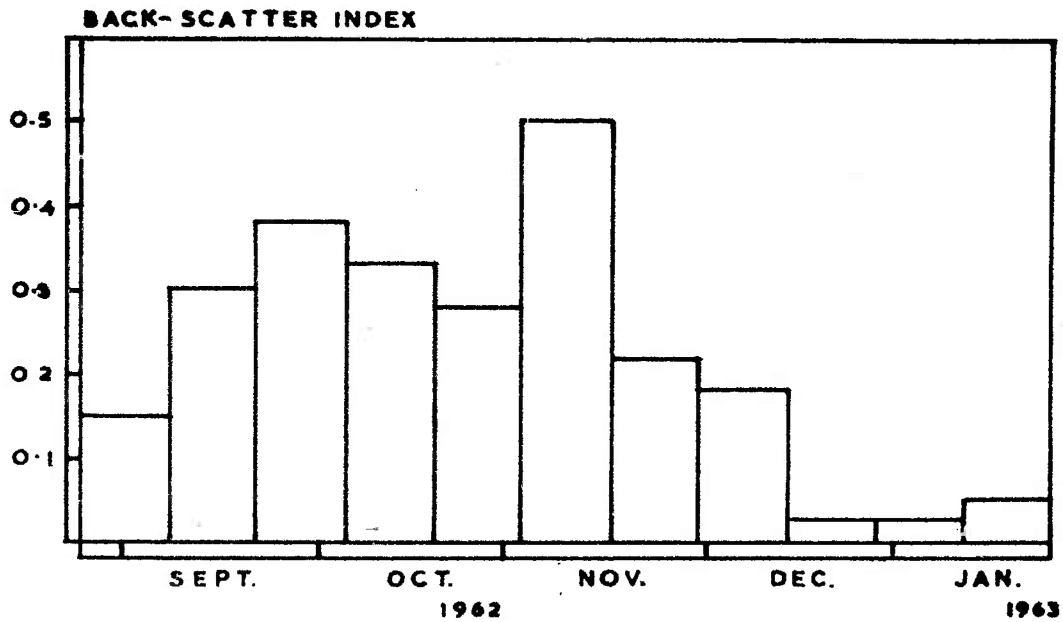

FIG. 5. SEASONAL VARIATION IN OCCURENCE OF DIRECT BACK-SCATTER

		SPREAD F	
		PRESENT	ABSENT
BACK-SCATTER	PRESENT	26 (20)	0 (6)
	ABSENT	11 (17)	11 (5)

FIG. 6. CONTINGENCY TABLE FOR OCCURENCE OF DIRECT BACK-SCATTER AND EQUATORIAL TYPE SPREAD F.

basis of equatorial type spread F occurring between 1800 and 2400 G.M.T., and as it is difficult to determine an index of intensity of spread F it has been made on the presence or absence of spread F only. The comparison is presented in Fig. 6 in the form of a contingency table, from which it may be seen that whilst direct back-scatter never occurs in the absence of spread F, scatter does not invariably occur when spread F is present. Over the period for which the comparison was made (October 28th to December 31st, 1962), scatter occurred on slightly more than 2/3 of occasions when spread F was present. In Fig. 6 the numbers shown in brackets are the frequencies to be expected if there were no connection between the two phenomena; the probability that they are independent is less than 1%.

3.4 Height of the irregularity patches responsible for direct back-scatter.

The height of a patch of irregularities may be determined when the patch is directly above the sounder, when the minimum range of the echo is equal to the height of the base of the patch. As the frequency used for sounding is much greater than the plasma frequency the effect of group retardation on the measured range is negligible, and the heights measured are, to a close approximation, true heights. Fig. 7 shows how the mean height of echoes varies during the period 1945 to 2145 local time, h'f curves are shown for comparison. It may be seen from Fig. 7 that heights vary from about 460 Km. at 1945, to 390 Km. at 2145, and are always 150 Km. above h'f.

3.5 Size of irregularity patches.

The fact that echoes are obtained from the east and the west, but not from the north or south is due to field alignment of the elongated irregularities responsible for the echoes, it being possible to obtain scatter only when the wave normal of the exploring wave is nearly perpendicular to the direction of elongation of the

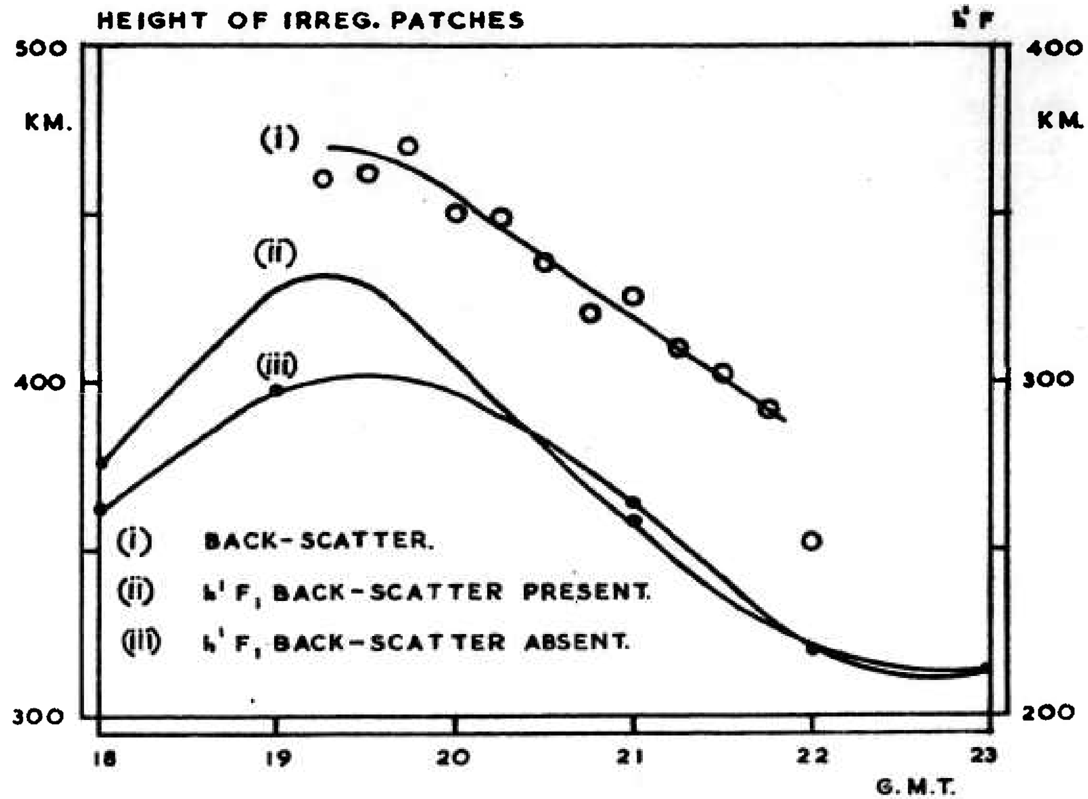

FIG. 7. NOCTURNAL VARIATION IN HEIGHT OF IRREGULARITY PATCHES AND h' F.

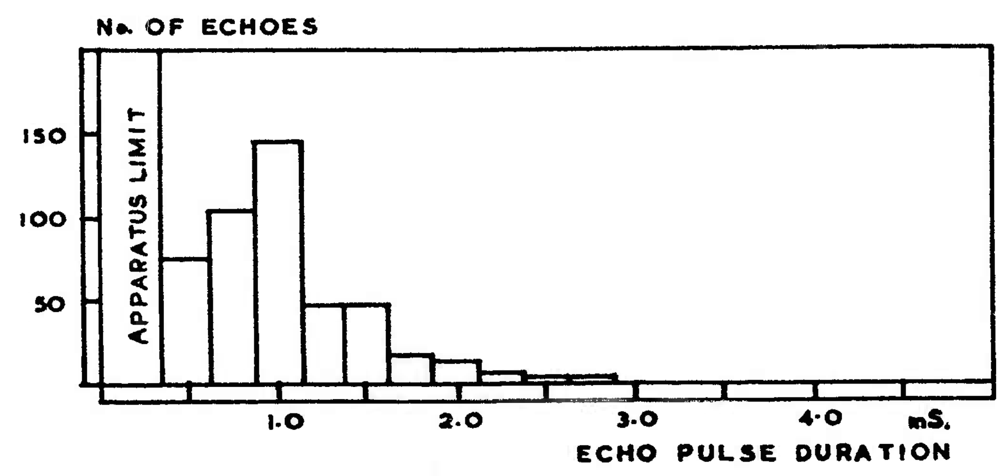

FIG. 8. DISTRIBUTION OF ECHO PULSE DURATIONS.

irregularities. As a consequence of the orthogonality requirement it is not possible to deduce anything about the north-south extent of the patches from the back-scatter measurements, but the duration of the echo pulse does provide some information on the extent of the patches in a direction normal to the direction of elongation of the irregularities. From the histogram shown in Fig. 8 it may be seen that the most probable duration is 1 mS.; as the duration of the transmitted pulse is 0.3 mS. the broadening of the pulse is 0.7 mS., corresponding to a patch size of approximately 100 Km. The largest patches observed are of the order of 400 Km. in extent, and the smallest are 30 Km. or less (patches smaller than 30 Km. might well exist, but the accuracy of the equipment is insufficient to measure ranges less than this figure).

If the cross-section of the patches in the east-west vertical plane is other than statistically isometric then the duration of echoes would be expected to vary with their range, i.e. a horizontally flattened patch would produce an echo whose duration increased with range, and a vertically elongated patch would produce an echo whose duration decreased with range. The mean echo durations for various ranges, east and west, have been measured and are plotted in Fig. 9. From Fig. 9 it may be seen that there is very little evidence of a systematic variation, the shortest durations occur at 9 mS. west and 4 mS. east, and although this could be the result of tilted flat patches, the evidence is too small to warrant any serious consideration of this possibility. The conclusion which must be drawn from the results shown in Fig. 9 is that there is no indication of a pronounced anisometry in the east-west vertical plane.

3.6 Drift of patches

The component of velocity of a patch of irregularities towards or away from the sounder may be obtained from the range/time records by measuring the slope of the echo trace. If it is assumed that the drift is horizontal then it is possible to calculate the horizontal velocity by assuming a height for the

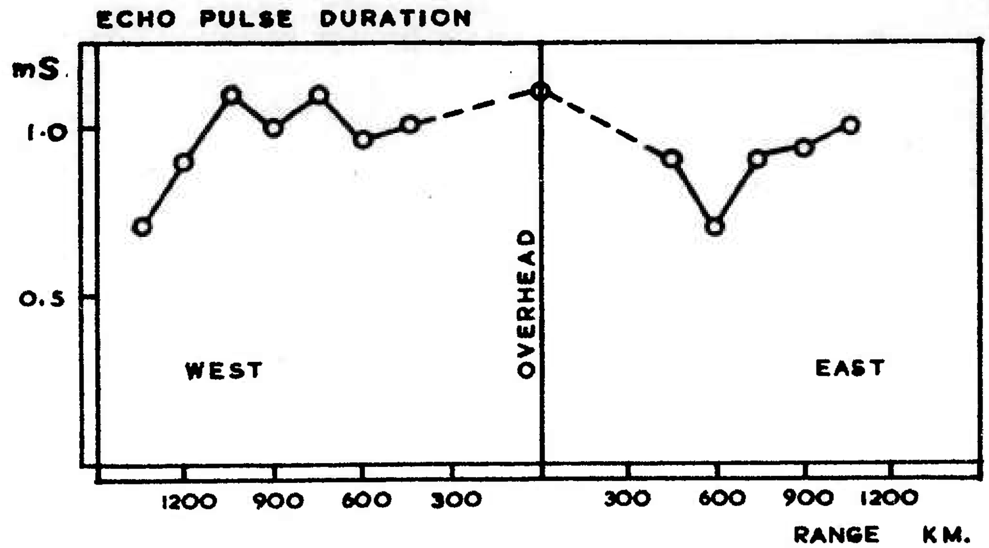

FIG. 9 VARIATION OF ECHO PULSE DURATION WITH RANGE.

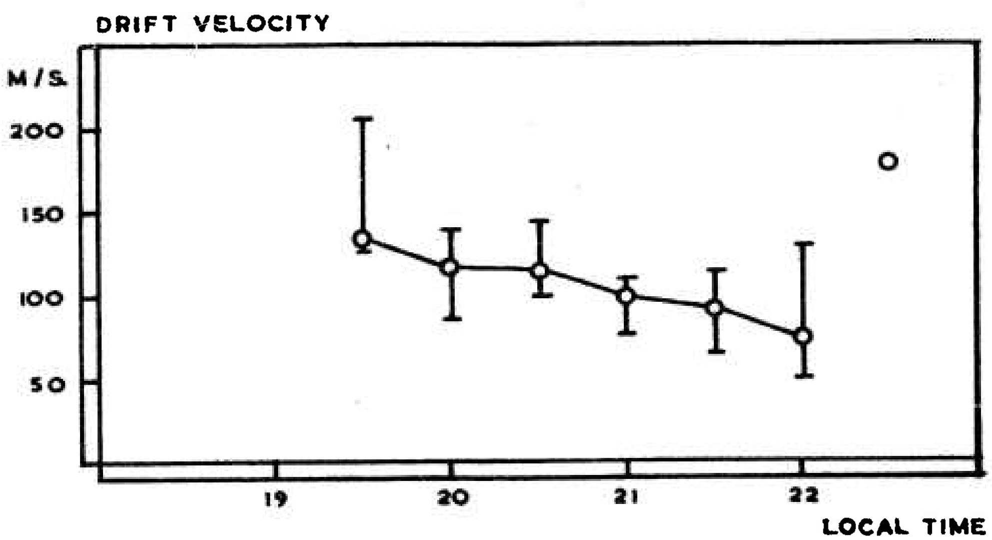

FIG. 10 MEDIAN DRIFT VELOCITY OF PATCHES.

patch; the error introduced by assuming a height which may be as much as 100 Km. too large or too small is only appreciable when the patch is nearly overhead, and hence drift velocities were only calculated for patches at ranges of 600 Km. or more, where the error in velocity would not exceed 10%. Another, and more serious, source of error lies in the fact that in calculating velocities the ray path in the ionosphere has been assumed to be a straight line, whereas in fact, for patches more than about 600 Km. away considerable refraction would occur unless the patch is close to the base of the layer. The effect of this, in conjunction with the small amount of group retardation which the wave suffers at heights near to h_m is to make the calculated velocities too high by as much as 25%. The median velocities at local times from 1930 to 2230, have been calculated from a total of 48 measurements, and are plotted in Fig. 10 (the time scale in Fig. 10 gives the local time at the position of the patch, which of course, is not the same as the local time at the sounder). From Fig. 10 it may be seen that maximum velocities of about 130 metres/sec. occur shortly after the irregularities first appear at about 1930 local time, decreasing to 75 metres/sec. at 2200, the very high velocity at 2230 is based on two measurements only, and is probably not typical. Although the velocities shown in Fig. 10 may be as much as 25% too high, this error applies equally well to all velocities, and so the decrease in velocity with time is probably real. The assumption of horizontal drift is justified by two experimental results: (i) P.P.I. records and range/time records for the same patch show that the rate of change of range with time is zero when the patch is overhead, (ii) the mean velocity, calculated on the assumption of horizontal drift, for patches seen to the east is not very different from that of patches seen to the west (120 m/s. east, and 103 m/s. west).

3.7 Doppler shift of echoes.

The construction of the equipment for measuring doppler shifts was not completed until towards the end of the autumn equinox period of 1962, when few direct back-scatter echoes were being observed, and hence only a few measurements have so far been possible. The line of sight velocities obtained from the doppler

shift measurements are plotted against range, east or west, in Fig. 11, which also shows the approximate width of the frequency spectrum of the echo pulse; the results shown in Fig. 11 were obtained between the hours of 2015 and 2130 G.M.T. on the nights of the 29th November and 1st December. The line of sight velocities of irregularities seen to the west of the sounder are of the order of 100 m/s. towards the sounder, which is approximately the velocity to be expected if the irregularities move at the same velocity as the patch, but irregularities vertically overhead show a velocity of 75 m/s. towards the sounder, and irregularities slightly to the east show a velocity of 50 m/s., still towards the sounder; these irregularities then were clearly travelling with a different velocity to the patch, unless the patch was behaving in a most unusual manner, as on no occasion has a patch of irregularities been observed to approach the sounder from the east.

The fact that the doppler shift decreases from west to east, but does not become zero overhead, strongly suggests that the irregularities have a horizontal component of velocity similar to that of the patches, but also have a vertical component directed downwards, which the patches do not exhibit. If this interpretation is correct, then doppler shifts produced by irregularities further to the east should be zero or negative; measurements to determine whether or not this is the case will be made during the 1963 spring equinox.

The spread in the frequency spectrum of the doppler shifted echoes represents a range of velocity of 20 to 50 m/s., such a range in velocity could arise in three different ways: (i) the irregularities might have a random component of velocity, (ii) the irregularities might be travelling all with the same velocity but in different directions, (iii) the irregularities might be travelling all in the same direction with the same velocity, but, as the patch subtends an appreciable angle to the sounder, the component of velocity of an irregularity towards the sounder would depend upon its position in the patch. As the manner

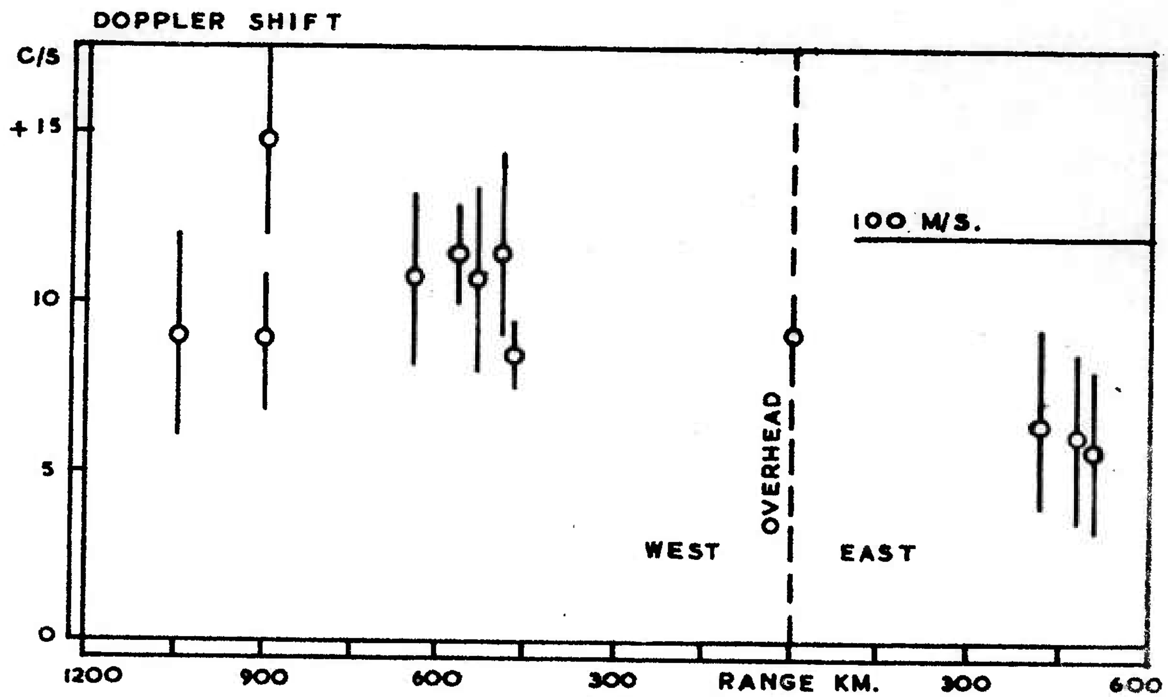

FIG. 11. DOPPLER SHIFT OF BACK-SCATTER ECHOES.

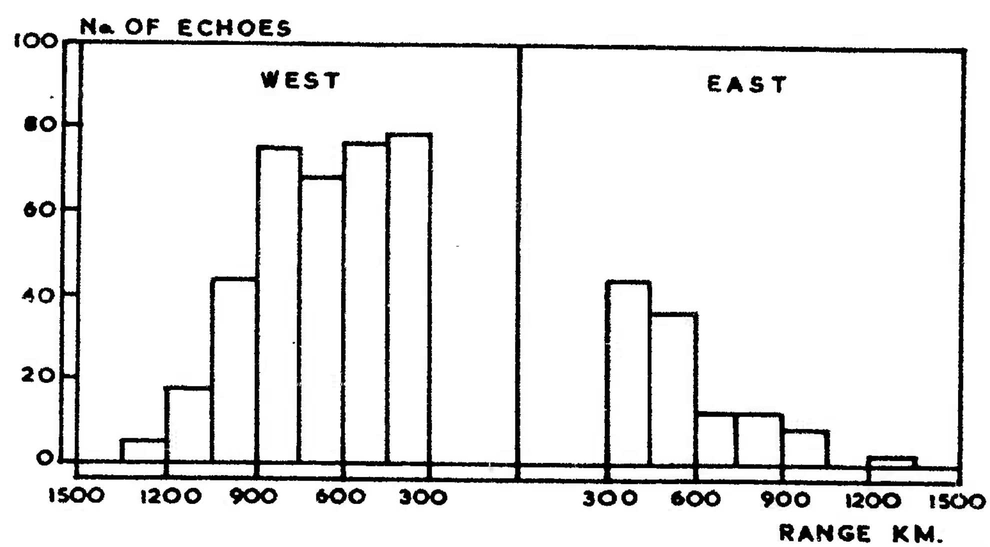

FIG. 12. EAST-WEST DISTRIBUTION OF ECHO OCCURENCE.

in which the spectrum of velocity components towards the sounder varies with range and patch size would be different for each of the above mechanisms, it should be possible to determine which mechanism, or combination of mechanisms is responsible for the spread in the spectrum. It is hoped that measurements made during the spring equinox of 1963 will enable this to be done.

3.8 Distribution of echo occurrence in the east-west vertical plane.

Whilst reducing the P.P.I. records it was noticed that many more echoes were observed in the west than in the east. In Fig. 12 the number of echoes seen at a given range, east or west, is plotted against range. Fig. 12 shows that during the period September to December, 1962, between three and four times as many echoes were observed to the west as to the east. This assymetry could be the result of a difference in the sensitivity of the sounder between east and west, but this would seem unlikely, as there is no noticeable difference between the strength of ground back-scatter signals seen to the east and to the west. Another possible cause would be a longitudinal variation in the occurrence of irregularity patches, again this seems unlikely in view of the very rapid variation with longitude which would be required. The third and most probable explanation is that the irregularities show an aspect sensitivity in the east-west vertical plane.

3.9 Duration of echoes.

The range/time records show the growth and decay of an echo, and hence make it possible to measure its lifetime. The life-times of some fifty echoes have been measured, and are shown in the histogram of Fig. 13. It may be seen from Fig. 13 that most echoes have lifetimes of ten to twenty minutes, but occasionally echoes are observed which endure for as much as ninety minutes.

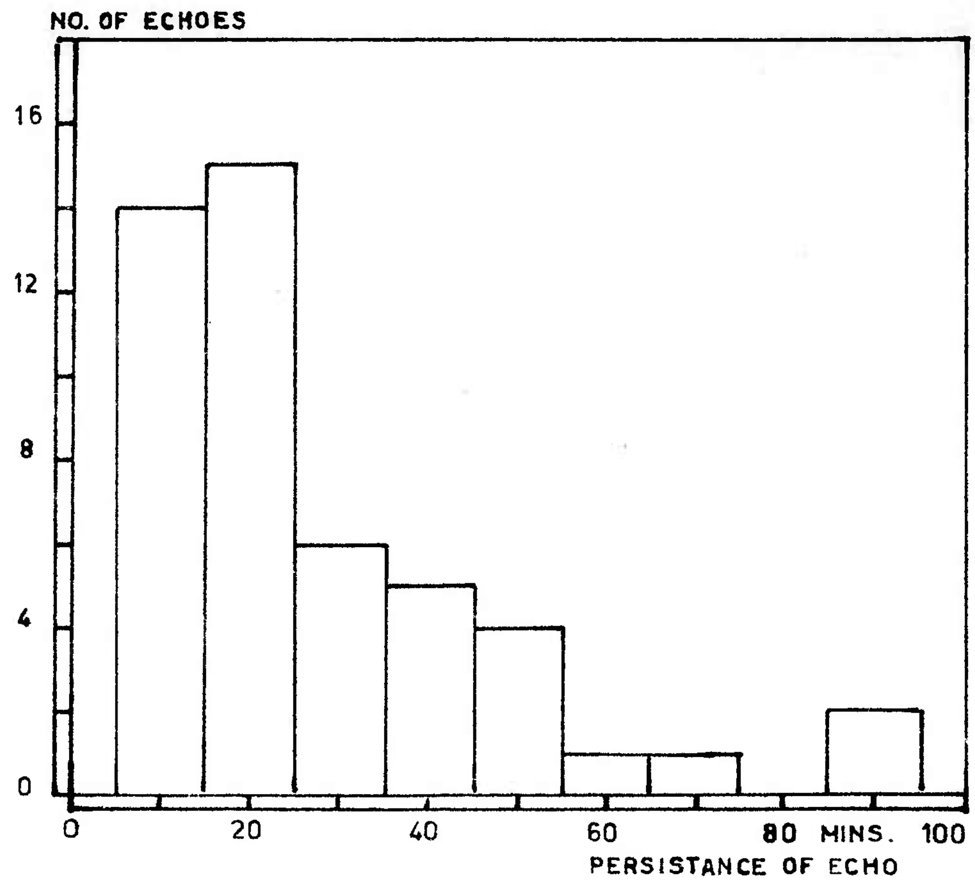

FIG. 13. DISTRIBUTION OF ECHO PERSISTANCES.

4. Discussion of Results.

4.1 Occurrence of irregularities.

The most immediately striking aspect of the occurrence of direct back-scatter echoes is the short period of time over which they are observed, the echoes nearly always occur between 1900 and 2200 local time, and approximately fifty per cent of echoes would appear to be formed between 1930 and 2030 local time. It was shown in Sect. 3.3 that there is a strong correlation between the occurrence of direct back-scatter and equatorial type spread F observed on a sweep frequency ionosonde, but although equatorial type spread F frequently continues until midnight, direct back-scatter is seldom observed after 2200 local time. It was also shown in Sect. 3 that direct back-scatter does not invariably occur on nights on which equatorial type spread F is present, and it would therefore appear that direct back-scatter is a special aspect of equatorial type spread F. Two other phenomena, which have been reported to occur at times closely corresponding to those at which direct back-scatter occur, are sunset 'flutter' fading, and abnormal doppler shift of obliquely propagated signals.

Calvert, Davies, and Koster (1962) have measured the doppler shift of signals propagated from Tripoli to Accra, and find that during the evening hours the normal smooth narrow trace on the frequency spectrum record spreads out to cover a range of 10 to 15 c/s.; they find the record to be most disturbed during the period between about 1900 and 2200 G.M.T. They also observe that there are striations running through the record, indicating one or more predominant frequencies which decrease with time, these they consider to be caused by patches of irregularities drifting from west to east. Calvert et. al. deduce velocities for the patches which show a tendency to decrease from about 130 m/s. at 1900 G.M.T. to 100 m/s. at 2400 G.M.T. Koster (1963) has reported that the rapid flutter fading (Subba Rao and Somayajulu, 1949, Osborne, 1951) which obliquely propagated radio signals frequently suffer when they are reflected from the equatorial F region at times around sunset,

occurs almost entirely during the period 1900 to 2300 local time for signals propagated between England and Accra, and that it shows a pronounced equinoctial maximum. Koster suggests that the rapid fading is due to the beating together of two signals, one propagated by a normal reflection process, and the other via a scatter mode, the signal propagated via the scatter mode having a doppler shift imposed upon it by the motion of the irregularities, as observed by Calvert, Davies, and Koster. In view of the similarity in time of occurrence, the equinoctial maximum, the similar east-west velocity, and the requirement of patchiness, it would seem to be almost certain that the irregularities responsible for direct back-scatter are identical in nature with those responsible for flutter fading and the doppler shift of obliquely propagated signals.

4.2 Properties of irregularities.

The height at which the irregularities responsible for direct back-scatter exist is approximately 150 to 300 Km. above h'f, which means that they are in the region of h_m, whereas the irregularities which cause spread F exist at all heights from h'f to above h_m (this has been shown by Calvert and Cohen (1961), who have synthesised equatorial type spread F records by assuming irregularities at given heights, and calculating the various permissable ray paths to and from the irregularities). The fact that the 18 Mc/s. signal of the back-scatter sounder is not scattered at lower heights can only be due to the fact that the gradients of electron density associated with irregularities at the base of the layer are insufficient to cause appreciable scattering at this frequency.

Cohen and Bowles (1961) have determined the height of irregularities responsible for transequatorial forward scatter of 50 Mc/s. signals, and found that they must exist at or below the base of the F region. Kent and Koster (1961) have measured the height of irregularities which cause scintillation of 108 Mc/s.

satellite signals at Accra, and find it to be between 50 and 100 Km. above h'f, and that the scattering layer is not more than 120 Km. thick. It is difficult to compare the scintillation studies with direct back-scatter results as the mechanisms involved are rather different, but the 50 Mc/s. forward scatter is more directly comparable. Cohen and Bowles state that irregularities with spatial wavelengths of 10 metres in the east-west vertical plane must exist at or as much as 100 Km. below the base of the F region, but not, apparently, at heights much above the base of the layer. From the appearance of spread F on normal ionograms it may be inferred that irregularities with dimensions up to at least 100 metres must also be present at the base of the layer, and thus it would be expected that irregularities of all sizes from at least 100 metres to 10 metres should be present at heights around h'f. The irregularities responsible for 18 Mc/s. back-scatter must have spatial wavelengths of the order of 20 metres, and it would therefore be expected that they would be observed at the base of the F layer, but this is not the case to any appreciable extent, the irregularities which cause 18 Mc/s. back-scatter are situated at heights of 150 to 300 Km. above h'f, where Cohen and Bowles apparently found no irregularities capable of supporting 50 Mc/s. scatter, and thus at first sight the 50 Mc/s. forward scatter measurements of Cohen and Bowles and 18 Mc/s. back-scatter results appear to contradict each other. A factor which to some extent reconciles these conflicting results is the difference between the height of the F region in 1958, at the peak of the sunspot cycle, when Cohen and Bowles made their measurements, and its height in 1962 when the measurements reported here were made. The height of the base of the F region for the period during which Cohen and Bowles observed forward scatter at 50 Mc/s. was about 400 Km., whereas the average value of h'f when 18 Mc/s. back-scatter was observed was less than 300 Km., and hence the difference in the absolute height of the bases of the irregularity patches observed by the two methods is not very great, although the difference in the height relative to h'f is considerable. Another contradiction for which no immediate explanation is apparent is that whilst Cohen and

Bowles find that irregularities exist in thin sheets, up to 1000 Km. in east west extent, and about 50 Km. thick, the 18 Mc/s. back-scatter results show that patches are normally about 100 Km. in east west extent, and are probably of equal vertical extent.

Lyon, Skinner and Wright (1961) have shown that under magnetically quiet conditions spread F is almost certain to occur when the height of the base of the F layer rises above 400 Km., and consider that if, as proposed by Dessler (1958), spread F is caused by hydromagnetic disturbances, this critical height would be explained by the fact that hydromagnetic waves would be attenuated rapidly at heights much below 400 Km., owing to the increasing collision frequency. These workers further suggest that the existence of a critical height would explain the seasonal, nocturnal, and sunspot cycle variation in the occurrence of spread F. The indication then, that the height at which irregularities in the F region are to be found does not vary with the sunspot cycle variation in the height of the layer, tends to support the hypothesis of Lyon, Skinner and Wright, but it must be remembered, however, that the nocturnal variation in the height of irregularities causing 18 Mc/s. scatter (Fig. 7) is almost identical with that of h'f, and therefore that, as far as the nocturnal variation is concerned, the height of irregularities is constant with respect to the layer.

The size of irregularity patches in the east-west vertical plane, observed by the direct back-scatter technique, varies from the limit of resolution of the equipment, of about 30 Km., up to about 400 Km., with a most probable value of 100 Km., and there is little indication that the patches are other than statistically isometric; no information is available about their north-south extent. The value of 100 Km. is in good agreement with that of about 100 Km. given by Kent (1961), for the size of patches of irregularities responsible for the scintillation of satellite signals at Ibadan. The conclusion that the patches have

approximately equal vertical and horizontal extent, and hence have a most probable thickness of about 100 Km. is not in agreement with the findings of Cohen and Bowles, who found that the irregularity patches responsible for forward scatter at 50 Mc/s. were not more than 50 Km. thick. Kent and Koster (1961), give an upper limit to the thickness of patches causing scintillation of satellite signals of 120 Km., but as they were unable to measure a thickness less than this it is difficult to make a comparison. It is perhaps important to emphasise here that the irregularities which cause 18 Mc/s. back-scatter are always observed in patches, and have never been observed to extend continuously over the whole sky.

The drift velocity of patches (Fig. 10) varies from about 130 m/s. at 1930 to 75 m/s. at 2200 local time. Lyon, Skinner and Wright (1962) have measured drifts at Ibadan using the spaced aerial technique, and obtain values of about 80 metres per second during the period in question, nearly always directed towards the east, but very occasionally towards the west even on magnetically quiet days. These workers find that the direction of drift changes from westwards to eastwards very rapidly at about 1930 G.M.T., and then steadily increases from about 50 m/s. at 2000 G.M.T to 100 m/s. at 2300 G.M.T., thus although the velocity and direction of drift measured by the spaced receiver technique at Ibadan are very similar to those measured at Accra by the back-scatter method, the manner in which the velocity changes during the evening is different; it should be remembered however that the measurements described in this paper were made four years after the Ibadan measurements. The measurements made towards the end of 1961 by Calvert, Davies, and Koster by the oblique incidence doppler technique are in better agreement with the back-scatter measurements. The velocities of about 130 to 100 m/s. obtained by these workers are very similar to the back-scatter results, not only in magnitude and direction, but also in the decrease of velocity with time, although the decrease observed by Calvert et. al. is not so pronounced. Calvert and Cohen (1961) have deduced drift velocities of patches of irregularities from sequences of ionograms taken at Huancayo, Peru, during 1960,

they find rather higher velocities than those measured at Accra, decreasing from 200 m/s. to 100 m/s. after 2100 hours local time, but with lower velocities sometimes occurring at earlier times.

The doppler shift measurements, the results of which were described in Sect. 3.7, indicate not only an eastward motion of the irregularities of the same order of magnitude as that of the patches, but also a vertical component of about 70 m/s. directed downwards. This downwards velocity is the result of a few measurements only, and requires to be substantiated by further measurements, but assuming that it is a normal occurrence it is of considerable interest. The irregularities which cause 18 Mc/s. back-scatter have been shown to exist at heights near to h_m, in which case, in view of their downward component of velocity it is possible that they are actually formed above h_m, subsequently drifting towards the base of the layer. This picture tempts one to suggest that the vertical motion of the irregularities is caused by the mechanism suggested by Martyn (1959), who has shown that an irregularity imbedded in the F layer would drift with a velocity relative to the layer given by $v = Ve/(2 + e)$, where V is the velocity of the whole layer in a downwards direction, and $e = \Delta N/N$, where N is the ambient electron density, and $N + \Delta N$ is the electron density in the irregularity. As a consequence of this effect irregularities above h_m would be enhanced when the layer is falling, and, as may be seen from Fig. 10, this is precisely the period during which irregularities are observed, furthermore, the irregularities (which, in order to drift downwards, would have to consist of 'holes' in electron density) would have their maximum relative intensity at h_m, which again is what is observed to occur. Unfortunately there are two objections to Martyn's mechanism as an explanation of the observed vertical velocity, firstly the velocity observed is much too large, and secondly, theoretical objections have been raised to Martyn's theory by Dougherty (1959) and Fejer (1959), which appear to show that an irregularity drifting in the manner described by Martyn would be unstable. It is possible to overcome the first of these two objections only if the ionisation is falling much more rapidly than the layer, the less rapid fall of the

layer being due to the vertical gradient in the recombination coefficient.

If Martyn's theory is correct then it would be expected that there would be a considerable distribution of velocities both vertically and horizontally, irregularities of different intensities drifting with different velocities. The width of the doppler spectrum represents a range of velocities of the order of forty metres per second, and, as explained in Sect. 3.7, this could represent a random velocity component, this again then is not incompatible with Martyn's mechanism. If the spreading of the doppler spectrum does in fact represent a random velocity component then it would be expected that the patch would in time disperse, and thus the short lifetime of patches may be the result of such a dispersion; however, the spreading of the doppler spectrum would represent a random velocity of only about one hundred kilometres per hour, which, in view of the fact that the mean patch size is of the order of 100 Km., is rather too slow to explain the average lifetime of about twenty minutes.

Whether or not the vertical motion of irregularities is due to the mechanism proposed by Martyn, the picture of 'holes' in electron density being formed above the maximum of the F region, and drifting downwards, could explain the lack of a vertical component in the drift velocity of patches. A 'hole' in electron density drifting through the region of h_m would have its maximum relative intensity, and hence involve the steepest gradients in electron density at this height, in which case it might only be in the region of h_m that it would be capable of scattering 18 Mc/s. signals; thus although the whole patch of irregularities might be drifting downwards, only that part of it near to h_m would be observed, and hence the observed patch would move down only with the velocity of the layer, which, being of the order of only 5 to 20 m/s., would not be observed on the range/time records. This mechanism of course automatically limits the period of time during which the patch is capable of causing 18 Mc/s. back-scatter, and thus provides another possible explanation for the relatively short lifetime of patches observed by the back-scatter technique.

In the foregoing discussion it has been assumed that the exploring wave is scattered by quasi-static irregularities in electron density, but it is possible that the irregularities are in fact the result of a wave motion, perhaps similar to the plane acoustic wavefronts which Farley (1963) has suggested for equatorial type sporadic E; some evidence in favour of a wave motion is given by the east-west assymetry in the occurrence of echoes described in Sect. 3. The doppler shift measurements indicate that the irregularities move downwards and eastwards at an angle of about 45° to the horizontal, if the irregularities are plane wavefronts, then maximum scattering would occur when the direction of the wavenormal of the exploring wave is parallel to that of the plane wave irregularity, and hence when the irregularity is to the west of the sounder at an elevation of 45°, and this is in fact approximately where most echoes are observed. Although the east-west assymetry in the occurrence of echoes provides some evidence in favour of a wave motion, it does not, of course, rule out the possibility of quasi-static irregularities, the shape of which is distorted by the electrodynamic forces involved in their motion across the earth's magnetic field.

5. Conclusions

1. Irregularities capable of producing back-scatter at a frequency of 18 Mc/s. occur almost exclusively during the period 1900 to 2200 local time, which is precisely the period during which the F layer is falling after its initial post-sunset rise; fifty per cent of irregularity patches are formed during the period of one hour from 1930 to 2030 local time. Most irregularities are observed at the equinoxes.

2. Irregularities are only observed when equatorial type spread F is present, being observed on about two-thirds of such occasions.

3. The irregularities always occur in patches, which may be up to 400 Km. in extent in the east-west vertical plane, with a most frequently observed size of 100 Km.; the patches appear to have approximately equal horizontal and vertical extent. The lifetime of patches varies from ten to ninety minutes, with an average value of about twenty minutes.

4. The height of the bases of the patches is usually about 150 Km. above h'f, and varies nocturnally with h'f.

5. The patches are observed to drift approximately horizontally from west to east with a mean velocity which decreases from 130 m/s. at 1930 local time to 75 m/s. at 2200 local time.

6. Individual irregularities appear to move with a different velocity to the patch, having approximately the same horizontal velocity, but also a vertical velocity of about 75 m/s. directed downwards.

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SOME MEASUREMENTS ON THE SUNSET FADING EFFECT

by

J. R. Koster

SUMMARY

The sunset fading effect, or flutter fading, is a phenomenon sometimes observed on radio signals reflected from the F region of the ionosphere when the reflection point is near the magnetic equator. The effect has been investigated in Ghana using direct observation of the carrier level, a fading rate meter and the doppler fading technique. It is found that flutter fading occurs between sunset and midnight, has equinoctial maxima, and correlates positively with the sunspot cycle. The fading rate is directly proportional to the frequency. It is suggested that coherent scatter from elongated irregularities could account for the observed correlation with radio star scintillations and for the doppler fading results.

SOME MEASUREMENTS ON THE SUNSET FADING EFFECT

1. INTRODUCTION

In 1949 Subba Rao and Somayajulu called attention to the occurrence of a sunset "flutter fading" effect observed at Andhra University in India. Somewhat later Osborne (1951) reported that near sunset at Singapore the F_2 layer frequently disintegrates into clouds of ionisation, and that under these conditions radio waves show very intense and rapid fading. The effect had, in fact, been reported as early as 1938 from Huancayo. Osborne suggested that the effect might well be observable shortly after sunset on certain days any place near the magnetic equator, where the magnetic dip is less than about 25°. He further found that the effect was a maximum at Singapore at the equinoxes, and he gave evidence that suggested that the occurrence is most frequent near the maximum of the solar cycle. In more recent years Hitchcock (1957) has reported severe post-sunset fading sufficient to degrade or to interrupt the service on 15 circuits operated by Cable and Wireless Limited where the transmission paths traverse low latitudes. Humby (1959) reported similar difficulty on trans-equatorial admiralty circuits, while Bennington (1960) has analyzed the severe fading experienced by the B.B.C. on their U.K./Johannesburg and U.K./Singapore circuits.

A peculiar evening signal enhancement referred to as the "Far Eastern anomaly" appeared quite regularly during experiments carried out by the National Bureau of Standards in the Far East during the I.G.Y. The effect was described by Bateman et al (1959) and attributed by Smith and Finney (1960) to reflection from field aligned ionization. Yeh and Villard (1958) have also described a type of fading of signals propagated on paths crossing the equator. They tentatively explained these in terms of a "tilt" propagation, but it is not impossible that reflection from field aligned irregulatiries may be involved here also.

The main characteristic of the sunset fading effect is described by the term "flutter fading", - a very deep and rapid fading of the signal. Voice transmissions seem to have a low audio frequency stutter, and the quality of music transmissions is ruined. During select periods, when no modulation is present, variations in the carrier level are heard as a low, semi-regular rumbling sound. A cathode ray oscilloscope connected to the detector of a receiver shows that the amplitude of the carrier wave is fluctuating rapidly at frequencies of a few tens of cycles per second.

2. OBSERVATIONS IN GHANA

In 1958 the occurrence of the sunset fading effect was quite frequent in Ghana, and it was noted that its presence seemed to coincide with an unusually severe type of radio star scintillation. Since this promised to throw further light on the latter rather puzzling phenomenon, an attempt was made to do some systematic observing of the effect. First investigations were made by ear, listening to the quality of the B.B.C. broadcast, and assigning a value of 0 - 3 depending on the amount of flutter fading judged present. This method proved rather subjective, however. Values assigned by independent radio amateurs participating on the observation programme showed a rather lower correlation than appeared consistent with meaningful results. Hence, during the vernal equinox, 1959, a C.R.O. display of the instantaneous carrier amplitude was photographed as a function of time on a continuously moving film. A twenty second sample was taken automatically at twenty minute intervals during the evening hours. In March, 1961, a fading rate meter of the type developed by the National Bureau of Standards was constructed and subsequently kept in continuous operation, monitoring the fading rate of the B.B.C. 15.07 mc/s. broadcast to West Africa. Receiver drift caused considerable initial difficulties, and rendered the results very unreliable. But when R-390/A receivers became

available through the Air Force Contract this problem was solved. The R-390/A receivers also make it easily possible to record the signal strength continuously through the monitoring of the ACC voltage. (See Fig. 1). In March, 1962, a second fading rate meter was put into operation to provide a continuous record of the fading of a broadcast signal originating locally.

During September and October of 1961 a transmitter on 19.904 mc/s. was operated at Tripoli, and recordings were made continuously at Accra using the doppler shift technique as described by Watts and Davies (1960).

3. RESULTS

3.1 The diurnal variation of flutter fading.

Early measurements showed that the phenomenon is normally observed only between sunset and midnight. Figure 2 shows hourly samples of the time variations in the detector voltage of a receiver tuned to the B.B.C. broadcast on 15.07 mc/s. The fades are very deep - right down into the noise, even though the mean signal strength remains high.

Figure 3 shows the mean fading rate for October, 1961. Although the B.B.C. continued their 15.07 mc/s. transmissions through the night for several months prior to November 1st, 1961, no post-midnight flutter fading was observed on any of the fade rate meter records.

3.2 The seasonal variation of flutter fading.

It was reported by Osborne (1951) that the fading of signals at Singapore was most frequent at the equinoxes. In Ghana an analysis was made of the results obtained on the fade rate meter which has been kept in continuous operation since March, 1961. We have defined "amount of flutter" for any given day as being the area under the fading rate curve. This was

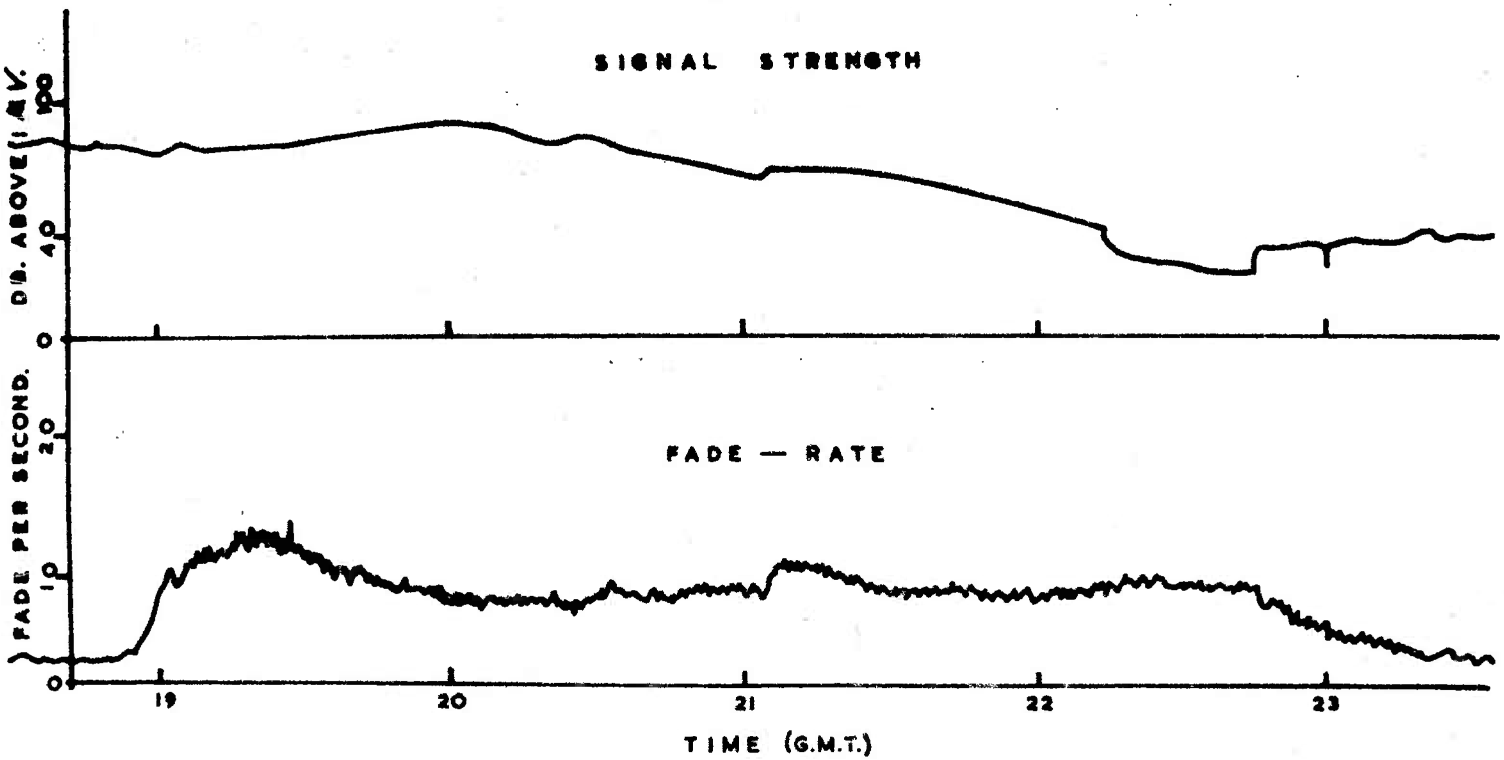

Fig. 1. Typical record of fade rate and signal strength of B.B.C. transmission on 15.07 Mc/s. during autumnal equinox.

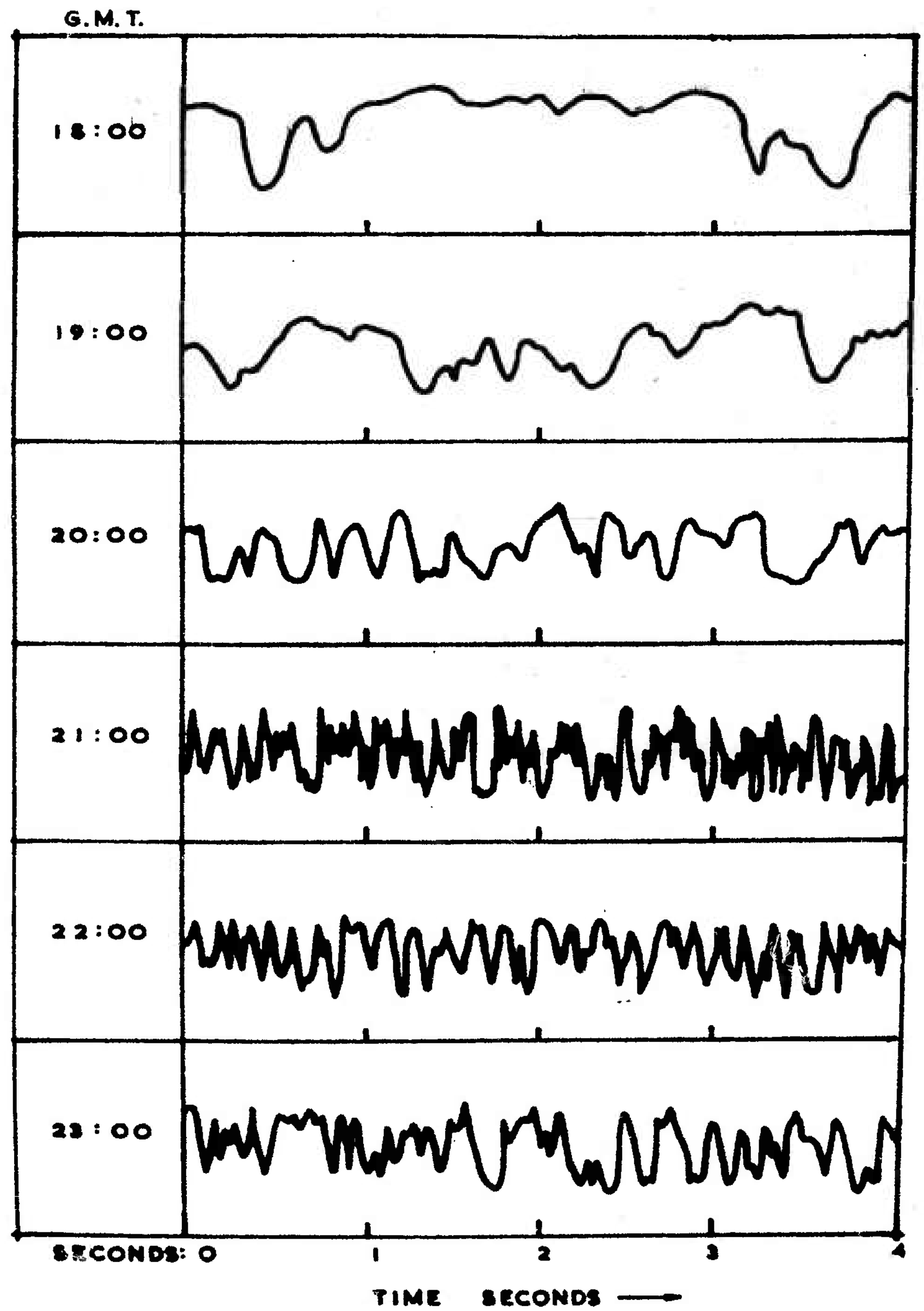

Fig.2. Hourly examples of detector voltage as function of time, showing severe flutter fading.

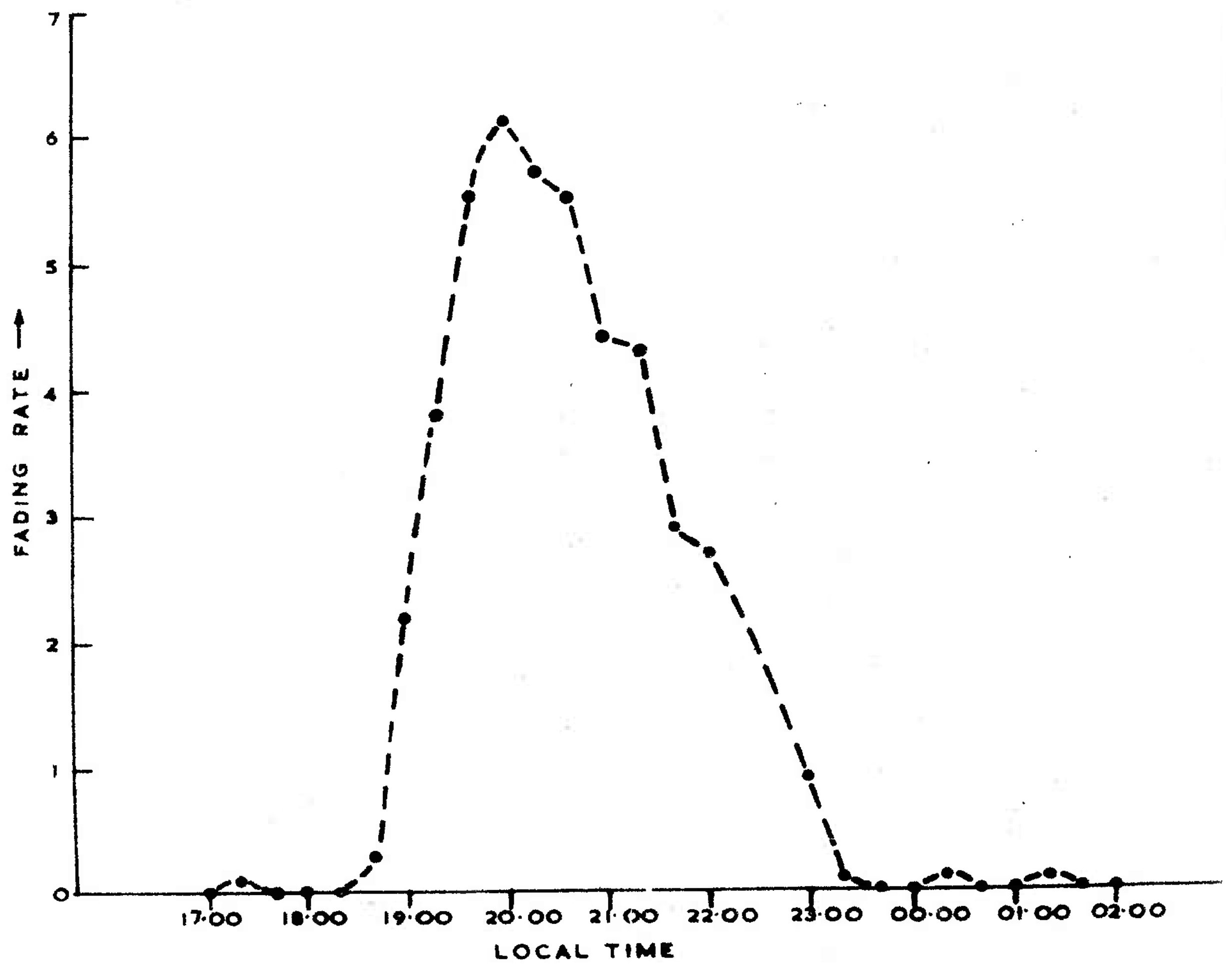

Fig.3. Mean fading rate versus time for October 1961.

estimated by determining a mean counting rate for each 20 minute interval on the records and summing them for the day. All fading rates of 2 per second or less were ignored. Also, all occasions were excluded on which the input signal to the receiver fell below the level of 20 db above one microvolt. This was done since it was found experimentally that when signals much below this level were received, background noise began to make substantial contributions to the output of the fade-rate meter. The results of the analysis are shown in Figure 4. It will be noted that definite maxima occur during the equinoctial periods. In both cases the maximum occurs well after the true equinox. This same displacement of the maximum from the equinox, it may be noted, occurs in the case of radio star scintillations. Its significance is not clear.

It also appears from the figure that the autumnal equinox shows significantly more flutter fading that does the vernal equinox. This agrees with radio star scintillation also.

The figure further illustrates the comparatively rapid falling off of the phenomenon as the sunspot cycle approaches minimum. The flutter fading recorded in the spring of 1962 is markedly less than that for the corresponding period of 1961.

The final analysis of the records for the latter half of 1962 has not been completed, but it can be stated that there was a marked reduction in the occurrence and severity of the fading. While other phenomena (radio star scintillations and back-scattered radar echoes) gave abundant evidence of the presence of irregularities over the equator at these times, there was virtually no flutter fading. The explanation of this is uncertain at the moment, and calls for further investigation. It is suggested, however, that it may be a result of a diminution in the width of the belt of equatorial irregularities.

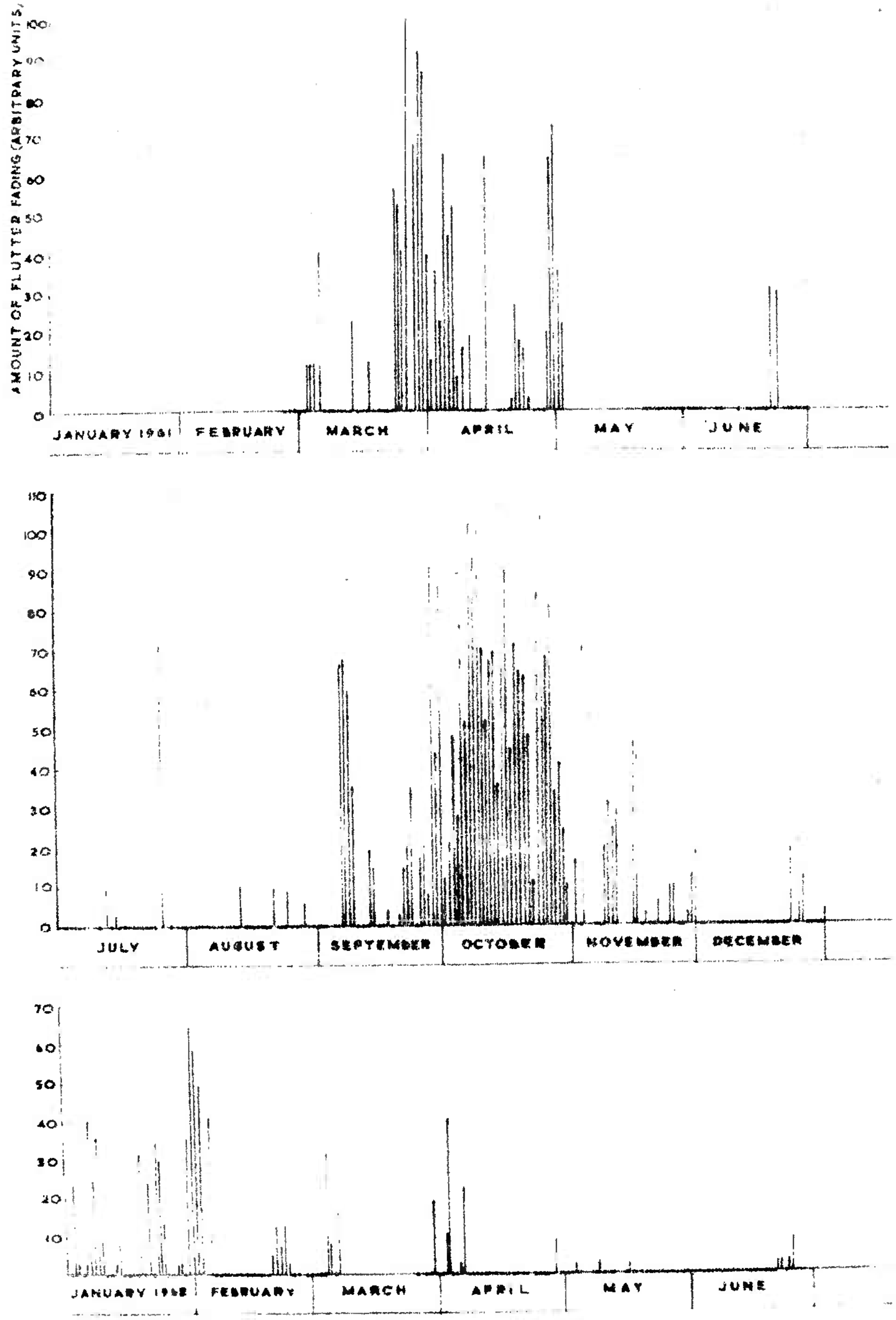

Fig. 4. Seasonal variation in amount of flutter fading.

3.3. The solar cycle dependence of flutter fading.

Sufficient data have not been obtained to plot a precise curve of the dependence of the sunset fading effect on the solar cycle. But the present observations, taken in conjunction with extensive but less systematic earlier observations in Ghana since 1958, tend to confirm the finding of earlier observers elsewhere [Osborne, 1951; 1952; Hitchock (1957); Humby(1959)] that there is a strong positive correlation between mean sunspot number and amount of flutter fading.

3.4 Flutter fading and radio star scintillations.

It has been pointed out elsewhere (Koster and Wright, 1960) that there is a high correlation between the occurrence of these two phenomena. To confirm this for more recent data, the mean F number for each of 4 consecutive twenty minute intervals from interferometer records of Cassiopeia at 108 mc/s were correlated with the corresponding mean fading rate of the B.B.C. signals. A correlation coefficient of 0.63 was obtained for 17 degrees of freedom. Flutter fading, like radio star scintillation, correlates negatively with magnetic activity.

The presence of considerable scintillation during the autumn of 1962, however, with an almost complete absence of flutter fading, shows that there is an additional factor operative in the case of flutter fading - possibly the north-south extent of the equatorial belt of irregularities as suggested above. This will be investigated further.

3.5 F ding rates at various frequencies.

The fading rate is best defined in terms of the time taken for the auto-correlation function to fall to a value of 1/2.

In the autumn of 1960 Ahafia made simultaneous photographic records of the fading of the same B.B.C. programme as received in Ghana on frequencies of approximately 7, 12, 15 and 21 m/sec.

His investigation shows an essentially linear relationship between fading rate and frequency. Hence the results are consistent with some form of doppler fading as the operative mechanism giving rise to the sunset fading effect.

3.6 Irregularities over Ghana.

It will be appreciated that the occurrence of flutter fading on a signal from London received in Ghana is evidence for the existence of ionospheric irregularities far to the North of Accra (1250 km. if the transmission is via a 2 hop mode; 830 if 3 hop). In order to see whether irregularities occur over Ghana itself at times when they occur thus far to the North, a second fade-rate meter was constructed and operated at Kumasi (270 km. N.W. of Accra) during the spring of 1962. The meter measured the rate of fading of a 5 mc/s. signal broadcast from Accra. The result is shown in Fig. 5.

A determination of the daily "amount of flutter" was made for both places, and the correlation coefficient calculated. For the fortnight following the vernal equinox a correlation coefficient of 0.44 (significant on the 8% level) shows that there is a considerable tendency for irregularities to appear over Ghana and over points about 1,000 Km. to the north of Ghana on the same nights. An hour by hour correlation between London and Kumasi fading rates yields a correlation coefficient of 0.52 for 78 degrees of freedom. This is highly significant, even on the 1% level, and would seem to suggest that the patches of irregularities frequently have a north-south extent considerably in excess of the 100 km. usually quoted in the literature.

3.7 Doppler fading results.

Doppler fading techniques were applied to a continuous wave transmission from Tripoli to Accra in September and October, 1961. These are reported more fully elsewhere, but it might be

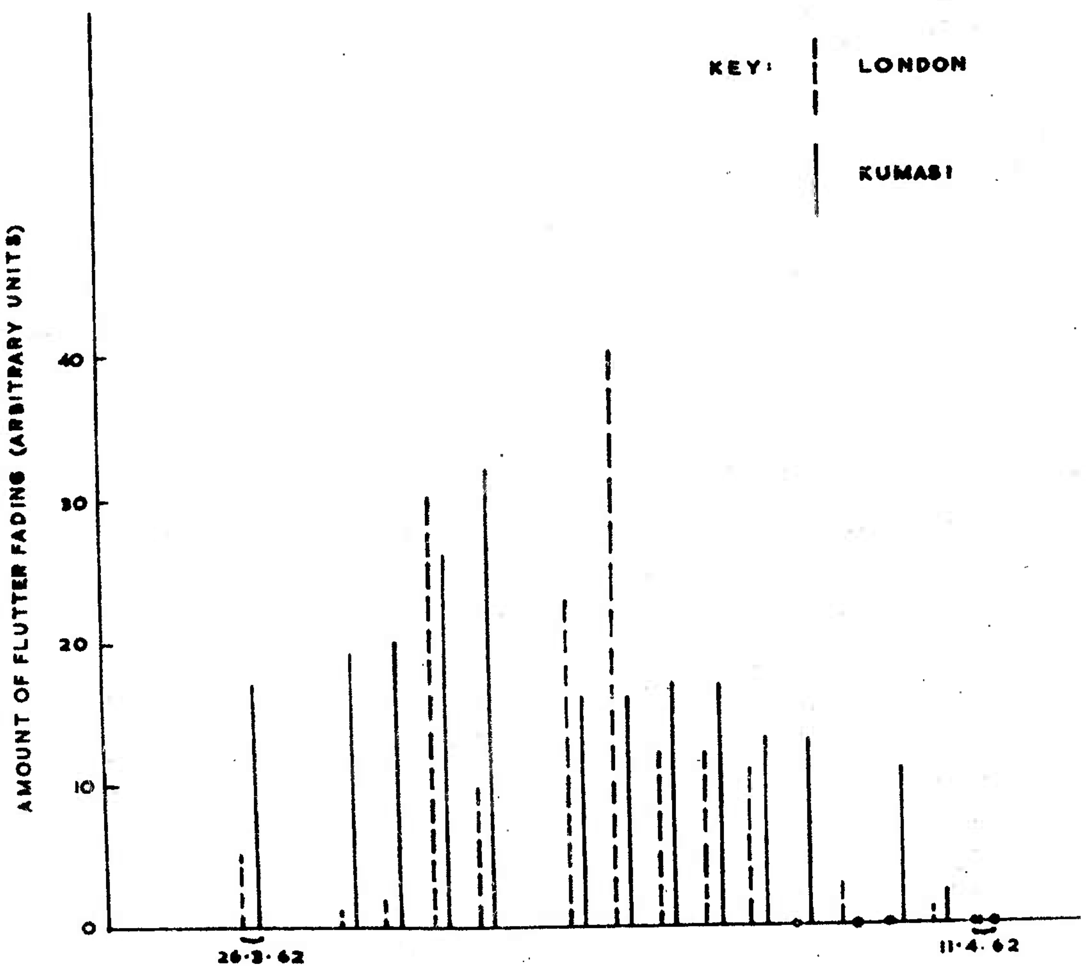

Fig.5. Comparison of amount of flutter fading on signals originating in London and in Ghana.

noted that the numerous and large doppler shift components recorded during the evening hours in this experiment are attributed to reflections from elongated irregularities so situated that the radio waves scattered from each show phase coherence over the entire length of the irregularity. There seems little reason to doubt that the sunset fading effect is due to the same mechanism.

3.8 Directional dependence of flutter fading.

During the 1960-61 academic year a widespread network of stations was monitored on most evenings to get some idea of the directional effect of the evening fading. When such fading occurred at all, it was usually observed to some extent on all the stations monitored. Frequently it was not particularly audible, but was readily visible on a C.R.O. screen.

Rather subjective observations seem to indicate, however, that the B.B.C. signals suffer more from this effect than equally strong signals from a westerly or easterly direction. It must be remembered that London is almost due north of Accra. It is suggested that the rather enhanced fading of the B.B.C. signals is due to a beating at a rather low audible rate, of a signal via the direct ionosphere path and one via a coherent scatter from elongated irregularities somewhat to the west of the direct path. The latter signal would, because of the drift velocity of the irregularities be doppler shifted somewhat. Since the paths are nearly of equal length, and both components are strong, the semi-regular fading which results should be more severe than that shown by signals received predominently by one or the other mode alone.

4. CONCLUSIONS

The sunset fading effect shows the same diurnal, seasonal and solar cycle variations as radio star scintillations at the equator. Both are apparently due to the same elongated F region irregularities occurring near the equator. Signals reflected from these elongated irregularities can be strong when the irregularity is orientated in such a way that a phase coherent signal is received from the whole length of the irregularity. This conclusion is strongly supported by doppler fading studies.

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SATELLITE STUDIES OF F REGION IRREGULARITIES AT THE EQUATOR

by

G.S. Kent and J.R. Koster

ABSTRACT

A preliminary report on experiments designed to investigate F region irregularities by measuring the fading of signals, from artificial earth satellites, at spaced receivers.

SATELLITE STUDIES OF F REGION IRREGULARITIES AT THE EQUATOR.

1. Introduction

This is a preliminary report covering a series of experiments performed during the last quarter of 1962. The experiments were carried out between 13th October and 23rd December, during which period observations were made on each night. All satellites having a transmission on the 136 to 137 Mc/s. band were used, and a total of more than one hundred records of moderate to severe scintillation were obtained. The satellites used included the following:

62 A EPSILON 1	Telstar	136.05
62 A ALPHA 1	Tiros 5	136.235 (136.922)
62 OMICRON 1	Ariel	136.408
62 ZETA 1	Orbiting Solar Observatory	136.744
62 BETA 1	Tiros 4	136.23 (136.92)
61 OMICRON 2	Injun	136.5
62 B LAMBDA	Explorer 15	136.101
62 B MU 1	Anna 1 B	136.815
62 B ALPHA 1	Albuette	136.979
62 A PSI 1	Tiros 6	136.235; 136.922

2. The experimental technique.

The experiments described in this report are basically similar to those made previously by Kent and Koster (1961), and were designed to provide a more thorough invdstigation of F region irregularities causing scintillation. In order to obtain information about the irregularities it is necessary to have a statistical description of the diffraction pattern produced on the ground by the passage of radio waves from an artificial satellite through the irregularities, and to

know how the diffraction pattern changes with time and the position of the satellite. The technique used was to measure the fading of the satellite signal at three or four spaced receivers and to record the fading at a central location.

Receivers were normally located at three stations, spaced to give a north-south baseline of slightly more than 2 km. and an east-west baseline of approximately 1 km.; the signals from these receivers were conveyed to the recording location via telephone cables. During the last weeks of the experiment a fourth station was added in order to provide a longer baseline in the direction of motion of the diffraction pattern over the ground; this being required in order to determine the thickness of the layer of irregularities. The spacing of the fourth receiver from the other three must be quite large, and as its required position differs for each satellite this station was made mobile, the signals being transmitted back to the central recording location via a radio link. Radio telephone links were used for coordination purposes between all stations.

The equipment used at each of the receiving locations consisted of the following:

(a) A simple 136 Mc/s. dipole made from one inch diameter steel tube, gamma matched to a fifty ohm coaxial cable.

(b) A low noise converter (Ameco, nuvistor convertor).

(c) A Collins R-390/A receiver.

(d) Provision for automatic control of the B.F.O. so that the receiver could be locked to the satellite signal in such a manner as to give a constant frequency audio output.

The audio signals from the receivers (each receiver was adjusted to give a different audio tone, and the tones selected so as to be unrelated to each other harmonically) were transmitted to a central recording location, where they were mixed together and recorded on one channel of a two channel tape recorder, time

information being recorded on the other channel. When the tapes were later played back for analysis the tones were separated by means of filter circuits.

3. Results.

The reduction of data has not yet been completed, and, partly because of the lack of computer facilities in Ghana at the moment (this lack will be overcome in October, 1963, when an IBM computer is to be installed in the Department of Physics), the analysis will take some considerable time. Selected parts of the data are at the moment being transferred from tape to paper using a visicorder, and scaled to digital form for computer analysis.

The following information is expected to be extracted from the data:

(a) The shape, size, and orientation of the diffraction pattern on the ground.

(b) The height of the irregularities in the ionosphere which give rise to the diffraction pattern on the ground.

(c) The thickness of the layer of irregularities.

4. Further experiments.

An insufficient number of records using a fourth station were obtained during the experiments described above, and for this reason further experiments are projected for the vernal equinox period of 1963.

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